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Wakamiya

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[54] **APPARATUS FOR CONTROLLING THE TEMPERATURE OF RODS IN A CONTINUOUS ROLLING MILL**

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[4] **G06F 15/46**; B21B 37/10

[52] **U.S. Cl.** **364/472**; 72/13; 72/201

[58] **Field of Search** 364/468, 469, 472; 72/8-14, 201, 236

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[57] **ABSTRACT**

An apparatus for controlling the temperature of a material being rolled into a rod in a rod rolling line having a continuous rolling mill with a first thermometer located at an inlet thereof, a plurality of water cooling units located at an outlet thereof and having an adjustable cooling water flow rate, and a laying head for winding the rod, the laying head having a second thermometer located at an outlet thereof. The apparatus comprises an arithmetic device for computing the rate of flow of cooling water based on a rolling schedule for the continuous rolling mill, an expected temperature at an inlet of the continuous rolling mill, and a target temperature at the laying head, and a control device responsive to a result of computation by the arithmetic device for controlling the rate of flow of cooling water.

3 Claims, 2 Drawing Figures

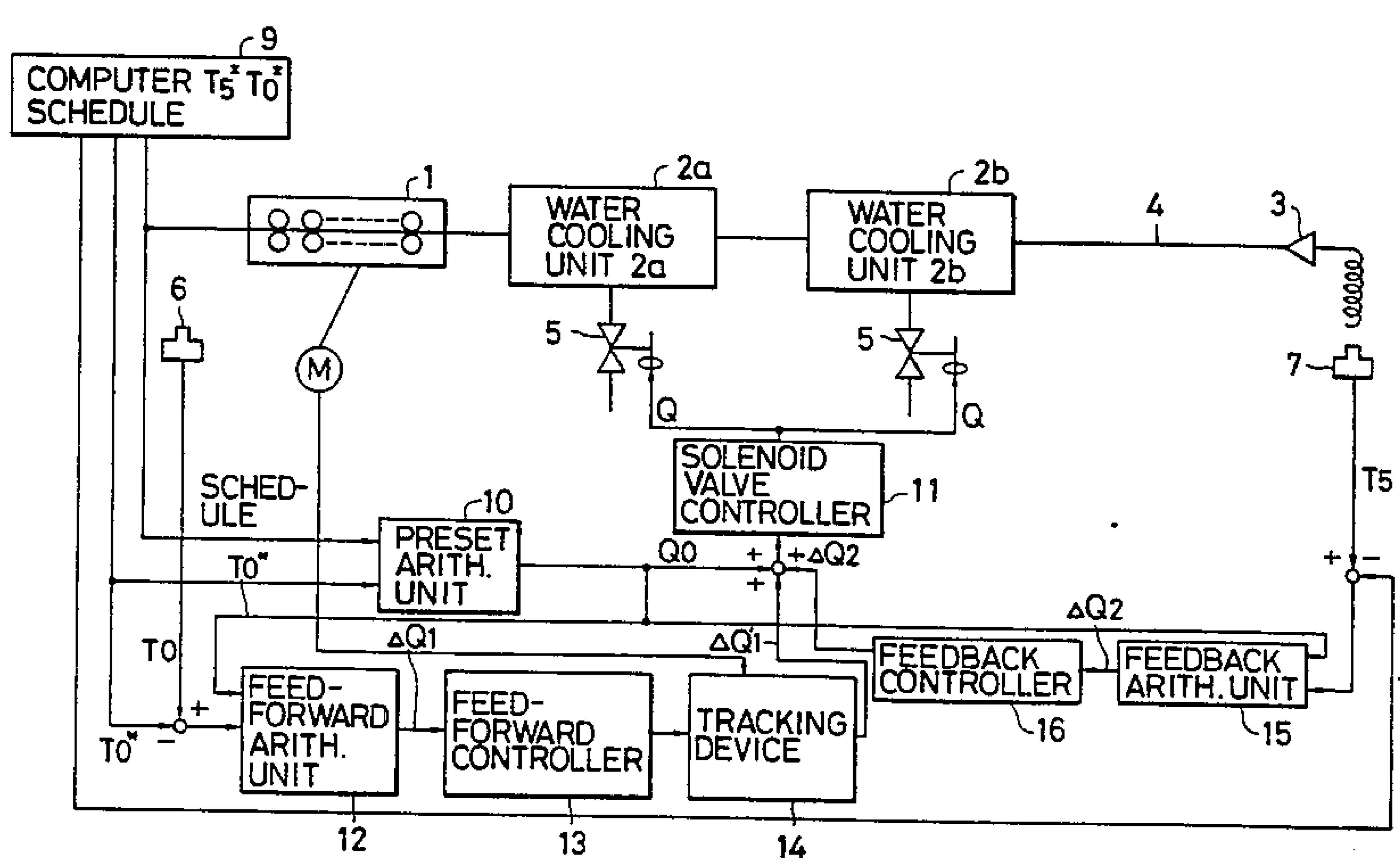


FIG. 1

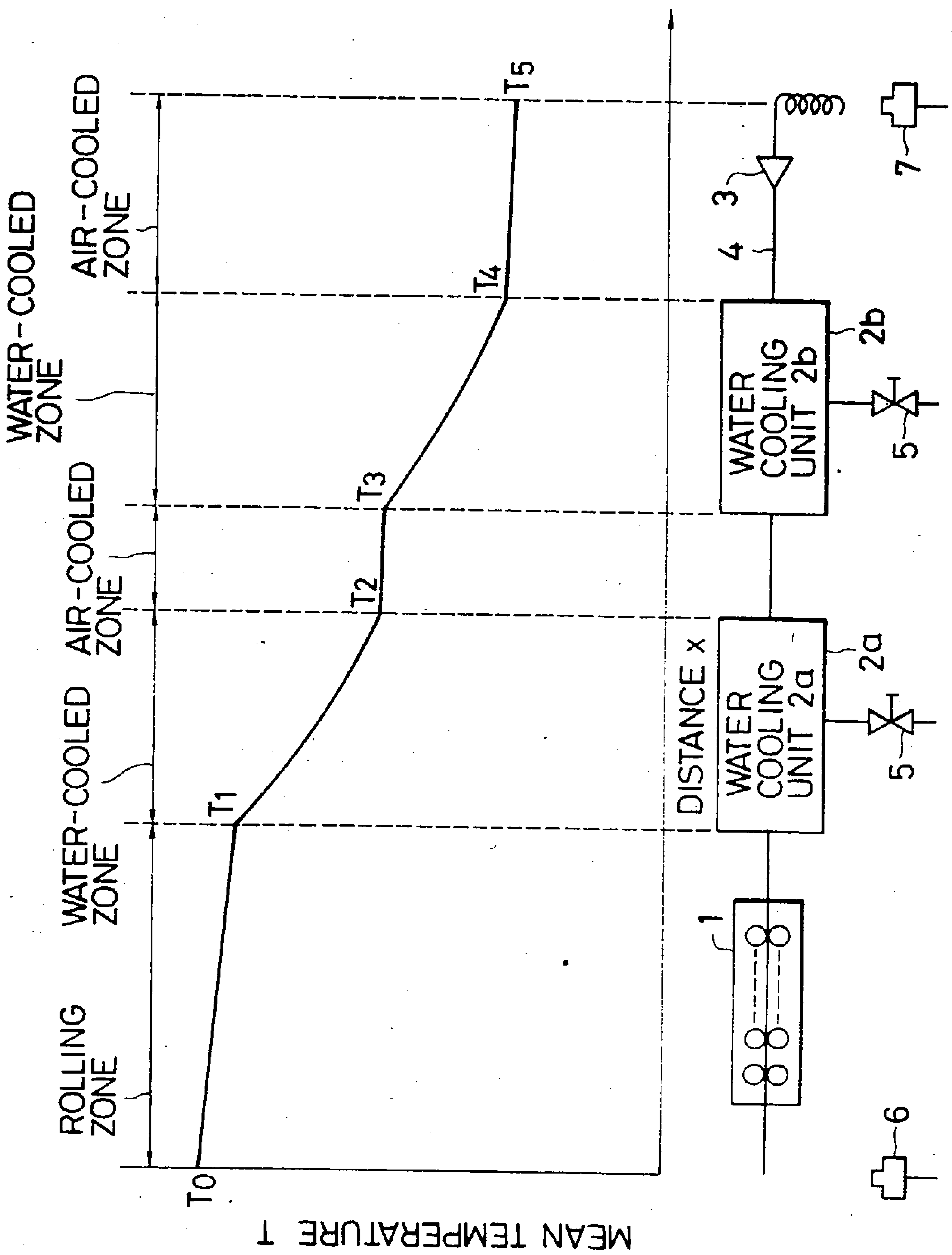
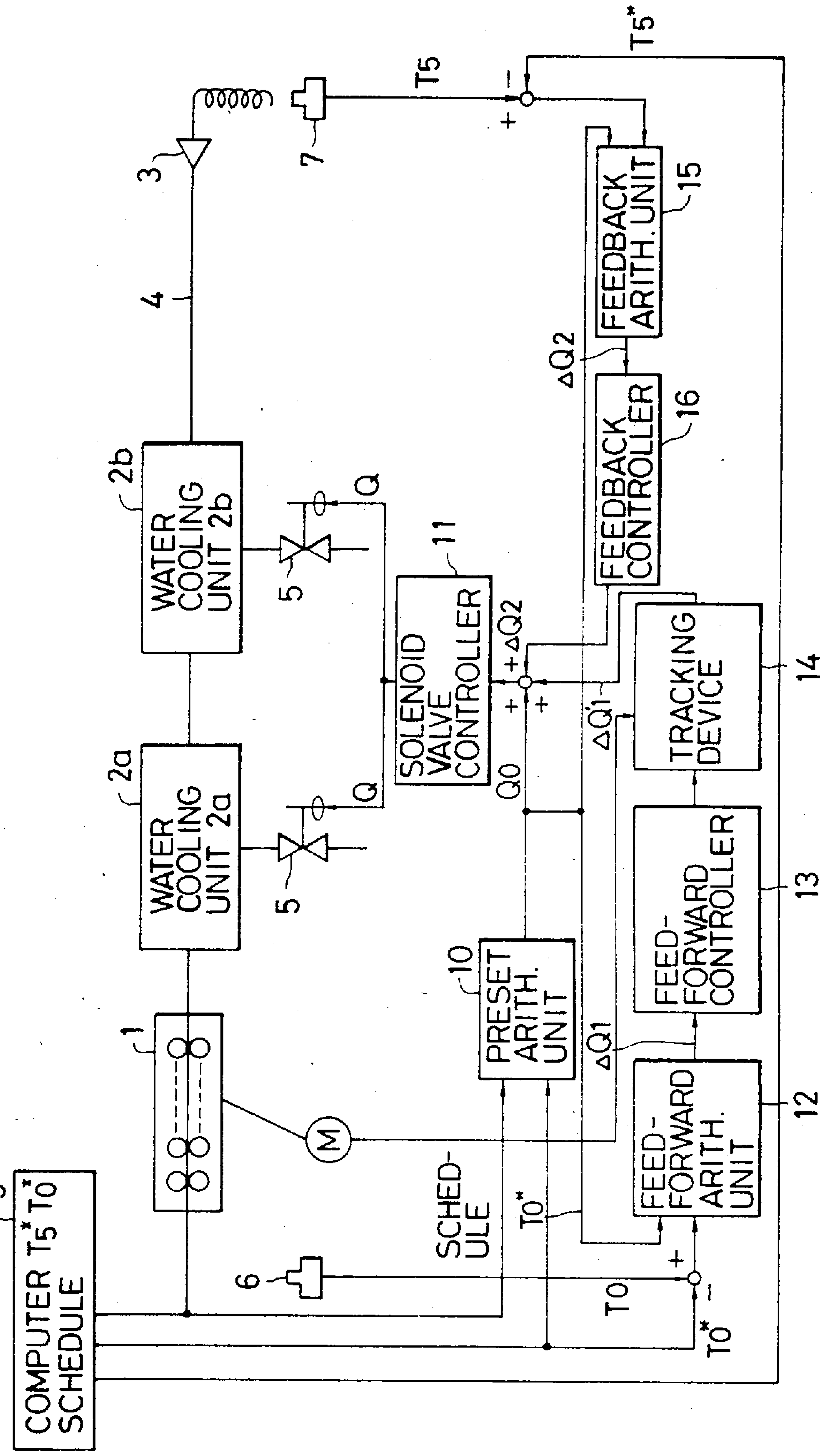

ROLLING ZONE
WATER-COOLED ZONE
WATER-COOLED ZONE
AIR-COOLED ZONE
WATER-COOLED ZONE
AIR-COOLED ZONE
T0
T1
T2
T3
T4
T5
MEAN TEMPERATURE T
DISTANCE x
WATER COOLING UNIT 2a
WATER COOLING UNIT 2b
1
2a
2b
3
4
5
5
6
7

FIG. 2


COMPUTER T_5^* T_0^*
SCHEDULE
WATER COOLING UNIT 2a
WATER COOLING UNIT 2b
SOLENOID VALVE CONTROLLER
PRESET ARITH. UNIT
FEED-FORWARD ARITH. UNIT
FEED-FORWARD CONTROLLER
TRACKING DEVICE
FEEDBACK CONTROLLER
FEEDBACK ARITH. UNIT
SCHED-ULE
T0*
T0
T5
T5*
Q
Q0
ΔQ1
ΔQ2
M

APPARATUS FOR CONTROLLING THE TEMPERATURE OF RODS IN A CONTINUOUS ROLLING MILL

BACKGROUND OF THE INVENTION

The present invention relates to an apparatus for controlling the temperature of a rod at a laying head of a rod rolling line so as to be in conformity with a target value.

Rod rolling lines have a plurality of water cooling units disposed behind a continuous rolling mill for rapidly cooling the rods as they emerge from the rolling mill, and then gradually cooling the rods to meet the requirements for the desired quality of the rod. It is important from the standpoint of rod quality that the temperature at which the rod begins to be gradually cooled after being rapidly cooled be brought into conformity with a target value in the longitudinal direction of the rod.

It has been customary practice for the operator to control the temperature at which the rod is to begin gradual cooling by determining the rate of the flow of water through the water cooling units while referring to a rolling schedule, and correcting the rate of the flow of cooling water based on his or her individual judgment, formed on the basis of the difference between the reading on a thermometer located on the laying head where the rod is to begin cooling, and target temperatures. The prior process has sometimes failed to select the rate of flow of the cooling water properly according to the rolling schedule, and has completely failed to control skid marks or temperature changes in the rod material.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide an apparatus for controlling the temperature of a material being rolled at a laying head so as to comform to a target temperature in the longitudinal direction of the material, by determining the flow rate of cooling water through water cooling units according to a rolling schedule for the material, and correcting the rate of water flow dependent on the difference between the temperature at an inlet of a continuous rolling mill and an expected temperature and the difference between the reading on a laying head thermometer and a target temperature.

According to the present invention, there is provided an apparatus for controlling the temperature of a material being rolled into a rod in a rod rolling line having a continuous rolling mill with a first thermometer located at an inlet thereof, a plurality of water cooling units located behind the rolling mill and having an adjustable rate of flow of cooling water flow rate, and a laying head for winding the rod, the laying head having a second thermometer located at an outlet thereof, the apparatus comprising an arithmetic device for computing the flow rate of cooling water based on a rolling schedule for the continuous rolling mill, an expected temperature at an inlet of the continuous rolling mill, and a target temperature at the laying head, and a control device responsive to a result of computation by the arithmetic device for controlling the rate of flow of the cooling water.

The above and other objects, features and advantages of the present invention will become more apparent from the following description when taken in conjunction with the accompanying drawings in which a preferred embodiment of the present invention is shown by way of illustrative example.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram showing rolling line components related to temperature control and mean temperatures of a material being rolled, respectively, at positions corresponding to the rolling line components; and

FIG. **2** is a block diagram of an apparatus for controlling the temperature of a material being rolled into a rod according to the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As shown in FIG. **1**, a continuous rolling line includes a continuous rolling mill **1**, first and second water cooling units ***2a, 2b,*** a laying head **3** for winding a rod **4** as it is produced, flow control valves **5** associated with the water cooling units ***2a, 2b,*** respectively, a thermometer **6** at an inlet of the continuous rolling line, and a thermometer **7** at the laying head **3**.

Mean temperatures T_0 through T_5 of the material being rolled are measured at the following positions on the continuous rolling line:

T_0 . . . the inlet thermometer **6**;

T_1 . . . the inlet of the first water cooling unit ***2a;***

T_2 . . . the outlet of the first water cooling unit ***2a;***

T_3 . . . the inlet of the second water cooling unit ***2b;***

T_4 . . . the outlet of the second water cooling unit ***2b;*** and

T_5 . . . the laying head thermometer **7**.

In FIG. **2**, the apparatus for controlling the temperature of the material being rolled comprises a computer **9** for generating an expected inlet temperature T_0^*, a target temperature T_5^* at the laying head **3** and a rolling schedule, an arithmetic unit (hereinafter referred to as a "preset arithmetic unit") **10** for computing an initialized rate of flow of cooling water, a controller **11** for controlling solenoid-operated valves based on a flow setting, an arithmetic unit (hereinafter referred to as a "feed-forward arithmetic unit") **12** for computing a corrected rate of flow dependent on a deviation in the reading on the inlet thermometer **6**, a feed-forward controller **13**, a tracking device **14** for tracking the material being rolled from the inlet thermometer **6** to the water cooling units to compute a time delay, an arithmetic unit (hereinafter referred to as a "feedback arithmetic unit") **15** for computing a corrected rate of flow based on a deviation in the reading on the laying head thermometer **7**, and a feedback controller **16**.

The operation of the control apparatus is as follows: An initial flow rate setting for the water cooling units is determined in the following manner. The computer **9** supplies the preset arithmetic unit **10** with an expected inlet temperature T_0^*, a target temperature T_5^* at the laying head **3** and a rolling schedule. The rolling schedule comprises:

(i) the diameter D_0 of the material at the inlet of continuous rolling stands;

(ii) the diameter di of the material at the outlet of the continuous rolling stands; and

(iii) the speed V of movement of the material at the outlet of the continuous rolling stands.

The preset arithmetic unit **10** computes a flow setting Q_0 in the following order:

(1) The temperature T_1 at the inlet of the first water cooling unit *2a* is computed from the expected inlet temperature T_0^* based on the equation:

$$T_1 = T_0^* - (\Delta Tp + \Delta Tf - \Delta Tc) \quad (1)$$

where

ΔTp: the temperature increase due to rolling operation in the continuous rolling mill;

ΔTf: temperature increase due to frictional heating in the continuous rolling mill; and

ΔTc: temperature drop due to contact with the continuous rolling mill.

These temperature changes ΔTp, ΔTf, and ΔTc are computed by the equations:

$$\Delta Tp = \frac{km \cdot lu\,(D0/dn)}{cp \cdot \gamma} J_1 \quad (2)$$

where dn is the diameter at the outlet of the continuous rolling stands, cp the specific heat, γ the specific weight, J_1 the coefficient of conversion from work into heat energy, and km the resistance to restrained deformation, which is a function of the temperature T_0^*.

$$\Delta Tf = \frac{(4p/\pi dn^2 V) \cdot J2 - km\ hn\ (D0/dn) \cdot J1}{cp \cdot \gamma} \cdot \beta \quad (3)$$

where p is the roller power of all of the rolling stands, J2 the coefficient of conversion from power into heat energy, and β the ratio at which the heat energy is distributed to the rolled material and the rolls.

$$\Delta Tc = \beta(T_0^* - Tr)\sqrt{\frac{k \cdot \Delta tr}{\pi}}\ \frac{8}{\overline{Dr}} \quad (4)$$

where Tr is the temperature of the rolls, k the temperature conductivity ($=(\lambda/cp \cdot \gamma)$, the thermal conductivity, Δtr the time required for the rolled material to move from the inlet thermometer **6** to the first water cooling unit *2a*, and $\overline{Dr}$ the mean diameter

$$\left(\overline{Dr} = \frac{1}{n}\sum_{L=1}^{n} di\right)$$

of the rod in the continuous rolling mill.

(2) Then, the temperature T_4 at the outlet of the second water cooling unit *2a* is computed using the laying head target temperature T_5^* by the following equation:

$$T_4 = T_5^* + \frac{4\sigma\epsilon\Delta t_{45}}{cp\gamma dn}\left(\frac{T_5^* + 273}{100}\right)^4 \quad (5)$$

where σ is the Stefan-Boltzmann constant, ϵ the coefficient of radiation of the rod material, and Δt_{45} the time required for the material to travel from the outlet of the second water cooling unit *2b* to the laying head thermometer **7**.

(3) Thereafter, a temperature drop ΔT_{23} due to air cooling at a point between the first and second water cooling units *2a, 2b* is found. Where the point is equidistant from the first and second water cooling units *2a, 2b*, the temperature T_2 at the outlet of the first water cooling unit *2a* can be expressed by:

$$T_2 = T_1 - \frac{(T1 - T4)}{1 + \sqrt{\dfrac{T4 - Tw}{T1 - Tw}}} \quad (6)$$

where Tw is the water temperature. The temperature drop ΔT_{23} can be expressed using T_2 as follows:

$$\Delta T_{23} = \frac{4\sigma\epsilon\Delta t_{23}}{cp\gamma dn}\left(\frac{T2 + 273}{100}\right)^4 \quad (7)$$

(4) From the foregoing, a total temperature drop ΔTwater at the first and second water cooling units is given by:

$$\Delta T\text{water} = (T_1 - T_4) - \Delta T_{23} \quad (8)$$

(5) The mean thermal conductivity h required for cooling the material by the temperature drop ΔTwater in the two water cooling units can be derived using the temperature T_1 at the inlet of the first water cooling unit *2a* as follows:

$$\bar{h} = \frac{cp \cdot \gamma \cdot dn}{2\Delta tw} \cdot l_u\left(\frac{T1 - Tw}{(T_1 - \Delta T\text{water} - Tw)}\right) \quad (9)$$

(6) It is known that the mean thermal conductivity h of the water cooling units and the flow rate Q have the following relationship:

$$h = AQ^B \quad (10)$$

where A, B are constants.

Hence, the flow rate setting Q_0 can be given by the following equation which is a modification of the equation (10):

$$Q_0 = \left(\frac{h}{A}\right)^{1/B} \quad (11)$$

With the flow rate setting Q_0 thus determined, the preset arithmetic unit **10** delivers this setting to the solenoid-valve controller **11**.

Flow rate correction through feed-forward control will be described for an instance in which the inlet temperature is different from the expected temperature T_0^* under the influence of a skid mark, thermal rundown, or the like. The feed-forward arithmetic unit **12** computes the difference between the actual temperature T_0 at the inlet thermometer **6** and its expected temperature according to the following equation:

$$\Delta T_1 = \left\{\frac{C}{T_0^{*2}}(\Delta Tp + \Delta Tf) - \frac{\Delta Tc}{T_0^*}\right\} \cdot \Delta T_0 \quad (12)$$

where ΔTp, ΔTf, ΔTc are temperatures computed by the preset arithmetic unit, and C a constant.

Then, a corrected value Δh for the mean thermal conductivity required to bring the temperature of the laying head into conformity with the target temperature is determined by the following equation, using the difference ΔT_1 as determined by equation (12):

$$\Delta h = \frac{cp \cdot \gamma \cdot dn}{2\Delta t} \cdot \frac{\Delta T_1}{(T_1 - Tw)} \tag{13}$$

A corrected rate of flow ΔQ_1 for Q_0 is determined by the following equation, using Δh:

$$Q_1 = \frac{Q_0}{B \cdot h} \cdot \Delta h \tag{14}$$

The feed-forward arithmetic unit **12** delivers as an output the corrected rate of flow ΔQ_1 to the feed-forward controller **13**, which effects usual P control based on the corrected rate of flow ΔQ_1 and issues an output value $\Delta Q_1'$ to the tracking device **14**. The tracking device **14** tracks the material from the inlet thermometer **6** to the water cooling units based on the number of RPM of the motor in the continuous rolling mill to compute a time delay, and adds the value $\Delta Q_1'$ to the flow rate setting Q_0 based on the computed timing and delivers the sum to the solenoid-operated valve controller **11**.

As described above, setting and correction effected by the preset arithmetic unit **10** and the feed-forward arithmetic unit **12** is of the open-type control. To compensate for this, feedback control is carried out on the basis of the difference between the reading on the laying head thermometer **7** and the target temperature T_5^* as follows:

The feedback arithmetic unit **15** derives a deviation ΔT_4 of temperature at the outlet of the second water cooling unit **2b** from the difference ΔT_5 ($=T_5 - T_5^*$) between the actual reading T_5 on the laying head thermometer **7** and the target temperature T_5^*.

$$\Delta T_4 = \frac{\Delta T_5}{\left\{1 - \frac{4}{100} \cdot \frac{6\epsilon\sigma\Delta t_{45}}{cp \cdot \gamma \cdot H}\left(\frac{T4 + 273}{100}\right)^3\right\}} \tag{15}$$

where T_4 is the temperature as computed by the preset arithmetic unit **10**. Using the temperature deviation ΔT_4, a corrected value Δh_2 for the mean thermal conductivity is determined by the following equation:

$$h_2 = -\frac{cp \cdot \gamma \cdot dn}{2\Delta t\text{water}} \cdot \frac{\Delta T_4}{(T_4 - Tw)} \tag{16}$$

A corrected rate of flow ΔQ_2 is determined by the following equation, using the above corrected value Δh_2:

$$\Delta Q_2 = \frac{Q}{h \cdot B} \cdot \Delta h_2 \tag{17}$$

The feedback arithmetic unit **15** delivers the corrected rate of flow ΔQ_2 as an output to the feedback controller **16**, which effects usual PI control based on the corrected rate of flow ΔQ_2, and then adds an output $\Delta Q_2'$ to the setting Q_0 and issues the sum to the solenoid-operated valve controller **11**.

While in the foregoing embodiment only two water cooling units have been described and shown, any desired number of water cooling units can be controlled by similar controlling arrangements of the present invention. In the illustrated embodiment, the expected inlet temperature T_0^*, the target temperature T_5^*, and the rolling schedule are delivered from the computer, these data items may as well be set up by the operator.

With the arrangement of the present invention, an initial setting for the rate of flow of cooling water for the water cooling units is made according to a rolling schedule without requiring the operator's manual operation, and the rate of flow is controllably corrected on the basis of the difference between a reading on the inlet thermometer and an expected temperature therefor and the difference between a reading on the laying head thermometer and a target temperature therefor. Accordingly, the temperature at the laying head can be kept very nearly constant.

Although a certain preferred embodiment has been shown and described, it should be understood that many changes and modifications may be made therein without departing from the scope of the appended claims.

What is claimed is:

1. An apparatus for controlling the temperature of a material being rolled into a rod in a rod rolling line having a continuous rolling mill with a first thermometer located at an inlet thereof, a plurality of water cooling units located behind said rolling mill and having an adjustable rate of flow of cooling water, and a laying head for winding the rod, the laying head having a second thermometer located at an outlet thereof, said apparatus comprising an arithmetic device for computing the rate of flow of cooling water based on a rolling schedule for the continuous rolling mill, an expected temperature at an inlet of the continuous rolling mill, and a target temperature at the laying head, and a control device responsive to a result of computation by said arithmetic device for controlling the rate of flow of cooling water.

2. An apparatus according to claim **1**, wherein said arithmetic device includes means for computing a corrected value for the rate of flow based on the difference between an actual reading on the first thermometer and an expected temperature at the inlet of the continuous rolling mill and a flow rate setting from the time when the material turns on the first thermometer, and wherein said control device includes means for correcting the rate of flow based on a result of computation by said first-mentioned means and for tracking the material from the first thermometer to the water cooling units to compute corrective timing.

3. An apparatus according to claim **1**, wherein said arithmetic device includes means for correcting the rate of flow based on the difference between an actual reading on the second thermometer and a target temperature therefor and a flow rate setting from the time when the rod turns on the second thermometer, and wherein said control devices includes means for correcting the rate of flow based on a result of computation of said first-mentioned means.

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